PREMATURE DECLINE AND DEATH OF TREES ASSOCIATED WITH A MAN-MADE LAKE AND GROUNDWATER WITHDRAWALS IN ALBANY, GEORGIA

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Abstract. Premature decline and death of associated trees had occurred on an Albany, Georgia tract within nine years following excavation of two man-made lakes, and withdrawal of ground water to augment water levels in the "lakes". Affected species included spruce pine (*Pinus glabra*), swamp laurel oak (*Quercus laurifolia*), overcup oak (*Q. lyrata*), and other hardwoods, such as sweetgum (*Liquidambar styraciflua*). Responses of the dead and declining trees were consistent with those reported at other sites where significant excavations and groundwater withdrawals have occurred. These responses could not be attributed to surface drainage, mechanical damage or disturbance, or natural phenomenon such as drought. The condition of the trees creates a hazard to property-owners, homes and any other structures that may be constructed on the proposed subdivision in the future. This situation also jeopardizes the intended market-ability of proposed subdivision lots as "forested". Similar impacts can be avoided in the future with a more comprehensive understanding of the interaction between aquifers and associated vegetation, and requirements to meter groundwater withdrawals.

INTRODUCTION

Site Description

Empirical data from a forested tract of land in Albany, Georgia provides additional support for the magnitude of impact that anthropogenic groundwater perturbations can have on the surrounding area. Inspections of the proposed Cedar Lake Subdivision were conducted on January 26, 1989 and May 31, 1989. Numerous small, shallow ditches were observed. These ditches had been constructed between November 11, 1969, and March 7, 1972, based on aerial photograph series AKW ILL and CS-VCXR, respectively. At the time of these inspections, no signs of stress were apparent in the forested wetlands that remained following the initial construction of the subdivision infrastructure. This observation provided strong evidence that the historic ditches, had not altered the wetland hydroperiod significantly, because the trees on the site were not exhibiting signs of stress approximately 20 years after ditch construction.

Project Design

During these site inspections, construction of the infrastructure had begun, in accordance with the design documents, including excavation of man-made "lakes". In May and June of 1986, approximately 51,740 cubic yards of soil were excavated during construction of a two-lobed man-made "lake" in the forested tract. The resulting excavated surface areas were 2.71 and 8.57 acres for the east and west lobes of the two-lobed man-made lake. Bottom elevations were approximately 182.5 ft. MSL and the designed static, "maintenance" elevation for the water level was 186.5 ft. MSL. The design criteria specified a water depth of 48 in., with an additional 24 in. of freeboard following construction. An associated forested wetland extended to the 190 foot MSL contour.

These excavations had occurred, in part, within the forested wetlands to provide artificial lake-front property for lots in the subdivision. The excavations had extended into the shallow water table (surficial aquifer), which was to be a source of water for the man-made "lakes", in addition to receiving untreated storm water.

The man-made "lakes" had been designed in such a manner that the "water table would be lowered by 24 inches", and that water levels in the man-made "lakes" would be "maintained by constructing a 6 inch, 220 foot-deep well" and pumping water from the [upper Floridan] aquifer, according to the "Albany Lakes Hydrology Report" by Post Buckley Shuh and Jernigan, Inc. (unpub., undated). In the fall of 1987, a well was constructed in the upper Floridan aquifer to maintain water levels in the man-made lakes. Declines in "lake" water levels exceeding 2 ft. were observed prior to pumping (D. S. McCoy, pers. comm., 1996).

Significant alterations of the natural hydroperiod should have been expected due to excavation of the man-made "lakes", and withdrawal of ground water from the underlying aquifer for augmentation of "lake" water levels. Hydroperiod alterations of this nature have resulted in premature decline and death of trees in the immediate area (Bacchus, 1990, unpub. data). A subsequent inspection was conducted to evaluate the condition of the surrounding area, as described below.

METHODS

The site was inspected on December 9 and 31, 1995, and April 2, 1996, to evaluate the general condition of the trees. These inspections occurred approximately 10 years after excavation of two man-made "lakes", portions of which had been a forested wetland, and nine years after construction of a well into the semiconfined, upper Floridan aquifer. The condition of the trees in close proximity to the excavated "lakes" was compared to the condition of the trees: 1) in other portions of the site, 2) adjacent to the site, and 3) from other sites in the southeastern Coastal Plain (SCP) where anthropogenic groundwater perturbations had, and had not occurred.

Trees that were exhibiting typical signs of decline (e.g., branch dieback, windthrow, basal or sucker sprouting, signs of saprophytic fungi) were identified. The approximate extent of areas where the signs of decline were observed were delineated in the field and on a 1988 subdivision plat map.

RESULTS AND DISCUSSION

Condition Analysis

The initial follow-up inspection to evaluate the condition of the trees was made on December 9, 1995. During that inspection, many of the trees within approximately 250 ft. of the man-made "lakes" in Cedar Lake Subdivision appeared to be dead or in various stages of decline which will lead to premature death of the trees. Those trees included spruce pines (*Pinus glabra*), swamp laurel oak (*Quercus laurifolia*), overcup oak (*Q. lyrata*), and other hardwoods, such as sweetgum (*Liquidambar styraciflua*). None of those trees exhibited lightning scars.

Adverse impacts to the trees could have been predicted based on: 1) engineering claims that the excavations would lower the water table and require augmentation via pumping of deeper ground water, and 2) hydrologic and ecological responses in other areas in the SCP to both small-scale and large-scale excavations into the surficial aquifer and/or withdrawals from the underlying, semiconfined aquifer (Bacchus, 1990; Bacchus, 1994; Curtis, 1984; Curtis, 1985; Curtis, 1987; Hicks *et al.*, 1987; Kimrey, 1990; Strack and Curtis, 1980). These responses were typical of stress responses described in the literature (Bertrand and Hadden, 1992; Hendrix, Jr. and Campbell, 1990; Manion and Lachance, 1992; Sinclair *et al.*, 1987).

A subsequent site inspection was conducted on December 31, 1995, to: 1) determine the lateral extent of dead and declining trees associated with the western man-made "lake", 2) inspect the remaining property for dead and declining trees, and 3) observe neighboring sites for dead and declining trees. The approximate lateral extent of the dead and declining trees observed around the western man-made "lake" was marked at the site as described previously. Similar patterns of premature death and decline were not observed in stands of trees with similar species composition on the same property, but at greater distances from the man-made "lakes", or on neighboring sites.

Dead Trees. Dead trees could be divided into two categories: 1) trees that remained standing, and 2) trees that had fallen. The standing trees had experienced severe branch/canopy dieback, leaving only the trunk and, on some occasions, reduced branches (Figure 1). Branch and canopy dieback are typical water-stress responses in trees. The fallen trees all exhibited decay (e.g., severing) of portions of the tap root or other major supporting roots (Figure 2). The pathological term for this response is "root rot". The condition is caused by fungi that digest the root tissue of living trees. Trees subjected to prolonged stresses, such as water stress, lose their natural defense mechanisms and become susceptible to attack by fungi that are present, but normally would not damage the trees (Bertrand and Hadden, 1992; Hendrix, Jr. and Campbell, 1990; Manion and Lachance, 1992; Sinclair *et al.*, 1987).

Declining Trees. Trees within approximately 250 ft. to the man-made "lakes" exhibited numerous symptoms of decline, including windthrow, branch and/or canopy dieback, sucker-sprouting, fruiting structures of saprophytic fungi, and Spanish moss in trees that were not post-mature. Windthrow occurs when the supporting roots or the base of a tree become severely decayed from fungi and the tree no longer can be supported in an upright position. The weight of the trunk and canopy of the tree cause the tree to start leaning, until the tree eventually falls to the ground (Figure 2).

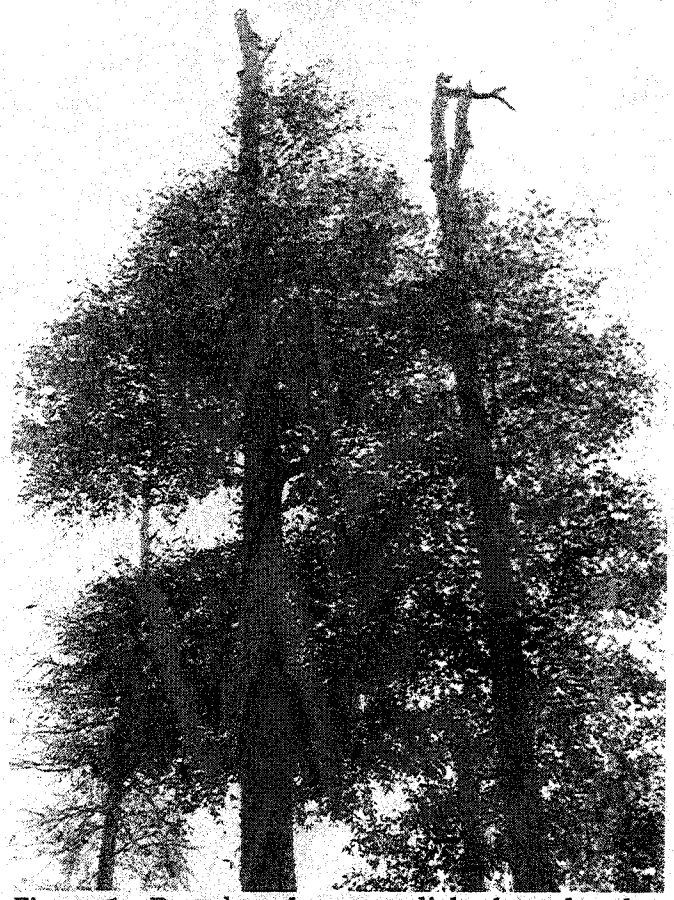

Figure 1. Branch and canopy dieback, and sucker sprouting in trees near man-made "lakes" in Albany, Georgia, USA.

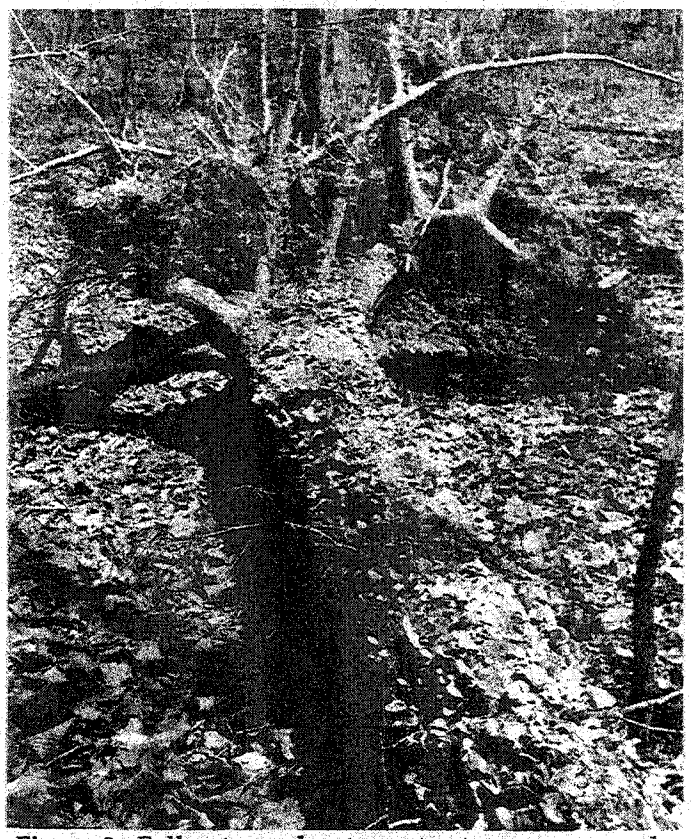

Figure 2. Fallen trees due to root rot near man-made "lakes" in Albany, Georgia, USA.

Branch/canopy dieback had occurred on the dead trees that remained standing and is apparent in many other trees that are still living (Figure 1). The cause of this type of decline is chronic stress that results in the tree transferring water and essential nutrients from active growth sites (branch tips) to interior portions of the tree for life sustaining activities. Sucker-sprouting is a response that often follows dieback. As water and nutrients are diverted from the tips of branches and the tops of the trees, the trees try to compensate for the loss of productive canopy by sending out new growth below the dead wood. The new shoots are called "sucker sprouts".

Saprophytic fungi are fungi that grow in and on dead plant material. They utilize nutrients from this organic material, which facilitates the decomposition process. These fungi are not aggressive, and generally do not attack or grow on living trees. Numerous trees in the vicinity of the man-made "lakes" exhibited copious quantities of fruiting structures of saprophytic fungi. The presence of these structures are indicative of the severe state of stress that these trees are experiencing.

Mistletoe is a parasitic plant with sticky seeds that sprout and grow in the canopy of stressed trees. Mistletoe survives by fusing with the vascular system of the host tree and removing nutrients and other essential components (Sinclair *et al.*, 1987). Several trees near the excavated "lakes" in the Cedar Lake subdivision contained excessive numbers of mistletoe plants in their canopy (Figure 3).

Spanish moss also appears in trees that are post-mature or in a severe state of decline (Bertrand and Hadden, 1992; Sinclair *et al.*, 1987). This epiphyte can be seen in many of the trees in close proximity to the man-made "lakes". The characteristics of these trees do not suggest a post-mature state.

Temporal Analysis

A third site inspection was conducted on April 2, 1996, to verify the previous determination and approximate the extent of tree death and decline at the western man-made "lake" and to perform a similar analysis at the eastern man-made "lake". The timing of this inspection followed the spring bud-break period. This time frame was selected to ensure that trees previously identified as dead or declining

were not healthy trees, exhibiting signs of new growth in the spring. The approximate lateral extent of the dead and declining trees observed around the eastern man-made "lake" was marked as described above.

Unsupported Causal Factors

Surface Drainage from Ditches. The ditches constructed across the property approximately 26 years ago are both narrow (approximately 4 ft. wide) and shallow (approximately 1.5 ft. deep). The elevational gradient of the ditch across the subdivision is approximately 1.5 ft. lower at the western boundary than at the eastern boundary (McCoy Engineering, Inc., unpub. plat map dated May 2, 1988). The shallow depth of the ditches results in limited interception and diversion of groundwater by the ditches. The width of the ditches exposes limited surface area for evaporation of surface water. The shallow slope of the ditches results in limited movement of water from the property except during periods of high rainfall when surface water levels are at a peak. This situation allowed sufficient water to remain within the root zone of the trees to maintain their health and vigor. This is evident by the fact that dead and declining trees were not observed at the site during the 1989 site inspections, approximately 20 years after the ditches had been constructed.

Figure 3. Mistletoe in canopy of trees near man-made "lakes" in Albany, Georgia, USA.

Mechanical Damage and Disturbance from Infrastructure. During the site inspections referenced above, each dead and declining tree was inspected for any signs of mechanical damage that may have occurred during construction of the infrastructure. Only a couple of trees that were located immediately adjacent to a small access road to the western "lake" exhibited signs of mechanical damage.

The approximate area containing the dead and declining trees also was examined for signs of mechanical disturbance that could have resulted in soil compaction and injury to the root system of the trees. Groundcover vegetation is very responsive to mechanical disturbance, in addition to hydroperiod disturbance. Species composition in the area inspected was dominated by species which are extremely sensitive to soil disturbance, such as partridge berry (*Mitchella repens*). The same area lacked typical species that are indicative of soil disturbance, such as dog-fennel (*Eupatorium capillifollium*), except around the margins of the excavations and roads.

Finally, the spacing between canopy and subcanopy trees is too small to have allowed access by heavy equipment that could have resulted in soil compaction or mechanical damage to trees within the designated boundaries. This observation and the existing species composition of the groundcover vegetation indicate that the cause of premature death and decline of the trees cannot be attributed to mechanical damage or disturbance during infrastructure construction at the site.

Mechanical Damage and Disturbance from Homes. The fact that the site has not experienced additional disturbance from the construction of homes following excavation of the man-made "lakes", and subsequent withdrawals of groundwater from the underlying, semiconfined aquifer, eliminates impacts associated with development stresses as a causal agent.

Natural Phenomenon. The trees that have died and are declining at the Cedar Lake Subdivision were/are in the canopy strata, rather than understory strata, indicating that available light was/is not a limiting factor for maintaining their vigor. These same trees were from peak productive size classes, indicating that death and decline could not be attributed to old age. They exhibited no lightning scars, eliminating lightning damage as a casual factor. The damage could not be attributed to natural cycles of below-average rainfall (drought) because trees at greater distances from the man-made "lakes" did not exhibit similar signs of death and decline.

Supported Causal Factors

Excavations. Approximately 51,740 cubic yards of soil were excavated during construction of the two man-made "lakes" in May and June of 1986, resulting in surface areas of 2.71 acres and 8.57 acres for the east and west "lakes", respectively. Bottom elevations of the "lakes" were approximately 182.5 ft. MSL and the designed static, "maintenance" elevation for the water level was 186.5 ft. MSL. The design criteria specified a water depth of 48 in. with an additional 24 in. of freeboard following construction", based on the "Albany Lakes Hydrology Report", Post Buckley Shuh and Jernigan, Inc., unpub., undated). The forested wetland extended to the 190 ft. MSL contour.

Excavation of the "lakes" created a larger, deeper area of intrusion into the surficial aquifer than occurred from construction of the ditches. Water in the surficial aquifer was occupying the pore space of the material that was excavated to construct the "lakes". After excavation, the pore space was converted into two enormous voids, the east and west man-made "lakes". The filling of these voids with water from the surficial aquifer resulted in a dramatic, permanent lowering of the water table. A sudden drop in the water table of this nature can increase the instability of subsurface strata, in addition to creating significant stresses to living organisms such as trees that are linked to the water table. The increased surface area of the "lakes" greatly increased water lost by evaporation. This loss, in conjunction with the permanent drop in the water table led to installation of wells to augment "lake" levels with ground water from the upper Floridan aquifer.

Groundwater Withdrawals. The well was not constructed until the fall of 1987, more than one year after excavation of the "lakes". Without supplemental water from the upper Floridan aquifer the lake levels may fluctuate from approximately two ft. below the minimum design levels to near-dry conditions (D. S. McCoy, pers. comm., 1996). The chemical influence of water pumped from the Floridan aquifer is evident by the extensive mineral precipitate and characteristic algal growth covering the margins of the man-made "lakes". Sinks or areas of subsidence were observed in proximity to the man-made "lakes". These responses are indicative of unstable subsurface areas susceptible to anthropogenic groundwater perturbations following excavations into the surficial aquifer or withdrawal of water from an underlying semiconfined aquifer. Unfortunately, Georgia laws do not require metering of groundwater withdrawals. Therefore, the volume of water withdrawn for a given period of time at this site (and most other sites) is unknown. This information represents a significant inadequacy in the water resource data base.

Semiconfined aquifers, such as the upper Floridan, also are called "leaky" aquifers (Hicks *et al., 1987*) because of the relative ease with which water moves between the surficial and underlying aquifers. Withdrawals from semiconfined aquifers can greatly increase both the rate and the volume of water moving from the surficial aquifer into the semiconfined aquifer. This phenomenon is called "induced recharge" or "capture" and can result in adverse impacts to associated wetlands (Kimrey, 1990).

The trees that had fallen exhibited extensive decay of the tap root, or other major roots providing nutrients and water to the tree, as well as support. Trees with these characteristics are common in areas of anthropogenic groundwater perturbations, where opportunistic fungi play an important role in the decay of tree roots subjected to abnormal fluctuations of the surficial aquifer. Many of the live trees that remained standing near the man-made "lakes" exhibited various symptoms of decline also typical of trees in areas of anthropogenic groundwater perturbations throughout the SCP.

Ramifications of Site Alterations

Additional Delayed Responses. Responses at other locations where anthropogenic groundwater perturbations have persisted for many years suggest that additional trees at the Cedar Lake site, exhibiting lower sensitivities to these perturbations, will experience premature decline and death in the future (Bacchus, 1995). These delayed responses can increase both the number of trees that will die prematurely, and lateral extent of the damage zone.

Hazards. The observed premature tree decline, in addition to the anticipated delayed decline of trees associated with the man-made "lakes", will create a hazard to property-owners, homes and any other structures that are constructed on this property in the future. Property-owners who construct homes on their lots generally are unaware of typical signs of premature decline in trees. As the condition of the declining trees worsens, these trees will pose a threat to homes or other structures on the lots.

Unforeseen Costs. The existing and continued premature decline of trees associated with the man-made "lakes" at the Cedar Lake Subdivision will require continual, selective removal of trees by future

residents of the subdivision to prevent damage to homes and any other structures added to the property. This will result in a considerable expense when individual trees have to be removed professionally to prevent damage to structures.

Marketing Subdivision Lots. To avoid the problems and liability described above, all trees would have to be removed from the lots prior to sale of the lots. This approach would not facilitate marketing lots because the lots were advertised as "wooded". This approach also would be contrary to the expressed intent of the owner stated in the "Protective Covenants" for the subdivision dated January 26, 1988, to prevent removal of any "living tree six (6) inches or greater at a point three (3) feet above the ground surface.....". Attempts to re-establish the natural forest cover (one of the advertised amenities of the property) may be circumvented because of the manipulated water table, ultimately requiring refilling of the "lakes".

SUMMARY

Many of the trees in close proximity to the man-made "lakes" in the Cedar Lake Subdivision have died, or are in various stages of decline, which will lead to premature death of the trees. The cause of death for the trees that have died cannot be attributed to old age or light deficiencies because the trees were from peak productive size classes in the canopy, rather than understory strata. The cause of premature death and decline of the trees also cannot be attributed to mechanical damage or disturbance during construction of access roads at the site, lightning strikes, or periods of low rainfall.

The trees that had fallen exhibited extensive decay of the tap root, or other major roots that provide nutrients and water to the tree, as well as support. This response is typical of trees in areas of anthropogenic groundwater perturbations, where opportunistic fungi play an important role in the decay of tree roots subjected to abnormal fluctuations of the surficial aquifer. Many of the live trees that remained standing near the man-made "lakes" exhibited various symptoms of decline also typical of trees in areas of anthropogenic groundwater perturbations throughout the SCP.

Similar patterns of premature death and decline were not observed in stands of trees with similar species composition: 1) on the same property, but at greater distances from the man-made "lakes", and 2) on neighboring sites. The observed distributional patterns support the conclusion that natural phenomena were not responsible for the premature decline and death of the trees associated with the man-made "lakes". Responses at other locations where anthropogenic groundwater perturbations have persisted for many years, suggest that additional trees at the Cedar Lake site, exhibiting lower sensitivities to these perturbations, will experience premature decline and death in the future.

The fact that the site has not experienced additional disturbance from the construction of homes following excavation of the man-made "lakes", and subsequent withdrawals of ground water from the underlying, semiconfined aquifer, eliminates from the list of causal agents direct impacts associated with development. The declining condition of these trees will create a hazard to people on the site and any homes that are constructed on this property in the future, in addition to subjecting any future home-owners to the expense of having the declining trees removed individually to prevent damage to structures added to the property.

Clearing all trees from the lots surrounding the man-made "lakes" to eliminate the hazards and liability would be contrary to the developer's intent of providing "wooded" lots to buyers. Attempts to re-establish the natural forest cover (one of the advertised amenities of the property) may be circumvented because of the manipulated water table and chemical changes in the water. Similar impacts can be avoided in the future with a more comprehensive understanding of the interaction between aquifers and associated vegetation, and state requirements to meter groundwater withdrawals.

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